ILC tracking
Si strip + gas micropattern detectors
(“Si++” variant)

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Snowmass, August 2005.
Tracking performance request and proposed variants

- track finding and reconstruction efficiency
- robust but low-mass construction
- $dP_t/P_t^2 \sim 6 \times 10^{-5}$
- alignment, calibration

- Perfect track finding / pattern recognition
- Good quality $P_t$ and $P_z$ reconstruction
- $dE/dX$ data

is it realistic to get a hit space resolution 
$\sim 100 \ \mu$m for so long (280 cm) drift distance?
- ExB corrections / alignment ( $B_z \geq 4$ T)
- space charge distortions; \( F(\text{drift distance, time structure, fluctuations}) \)
- field cage and construction materials thickness
- membrane (cathode) HV; 
  if $E>350. \ \text{V/cm} \rightarrow V_c > 100. \ \text{kV}$

TPC based tracking

O(200) points on TPC track
5 layers of pixel VTX detector
O(2) Si-tracking layers

mixed TPC based solutions: LDC, GLD

rely heavily on large volume gaseous tracker as "seeder"
do primarily outside-in tracking
supplement by precision VTX detector plus (possibly) intermediate Si layers
heavily influenced by LEP experience with gaseous trackers
Tracking performance request and proposed variants

- track finding and reconstruction efficiency
- robust but low-mass construction
- \( d\text{Pt}/\text{Pt}^2 \sim 6 \times 10^{-5} \)
- alignment, calibration

- Fast and reliable
- Perfect Pt reconstruction
- Compact set-up

SI-based tracking:

- 5 layers of pixel detector
- 5 layers of SI-strip detectors

All-SI solution: SiD concept

- rely heavily on VTX detector as track "seeder", do inside-out tracking
- use additional SI detector as "mementor" and "linker"

- Track finding and pattern recognition
- Rely on VXD or EMC data / performance
- Pz, track matching performance

heavily influenced by good SLD VTX detector experience
SiD and VXD in GEANT

In Barrel:
Si-strip detectors: single-sided, 300 μm thickness, 10x10 cm² size
Si-pixel (CCD, APS, …): 100 μm thickness, 20x20 μm² pixel size
no construction materials, FEEs, Cables, …. 

In Forward Direction:
Si-strip detectors, double-sided with stereo angle
Triple GEM detectors (TGEM) with stereo-strip readout, E||B
Simulation steps

- One particle ($\pi$) per event
- $B_z = 4$ T
- Primary Vertex is in a Fit

1. - GEANT hits (points in a space)

2. - Interaction probability
   - Position along the track
   - Energy transferred
   - $Te^-$, Range, $Ne^-$
   - Diffusion, drift time
   - Q on strip (pad)
   - Noise, FEE response

3. Cluster finding
   Hit position reconstruction (CG or $\eta$–algorithm)

   The same approach for TPC response simulation

   For “CCD” simulation – pad selection

   For TGEM gas detectors – hits smearing

4. Helix Fit; $Pt$, $Pz$, DC$Axy$, $rz$
Si-strip, 50 μm pitch, hit position resolution

5 layers \(\rightarrow\) sometimes 4 hits;
efficiency, \(\delta\)-electrons, broken or “dead” channels,
Lorentz angle, ….

![Graph](image-url)
PLUS miniTPC or triple GEM detectors with stereo-strip readout

**miniTPC:**
- Micropattern readout, 30 pad-rows, max drift distance: ~90 cm.
- Fast, low diffusion "working" gas, max drift time: ~10 μs.
- Low-mass construction: "no wires – no frame", field cage and gas windows are different parts.

**GEM Detectors (COMPASS):**
- Gas micro-pattern strip (stereo) detectors demonstrated very good performance.
- Low mass (and cost), fast, reliable, with space resolution ~40 μm.

**Equations:**
- $R_{in}=50 \text{ cm}$
- $R_{out}=85 \text{ cm}$
- $R=120 \text{ cm}$
PLUS miniTPC or triple GEM detectors with stereo-strip readout

N of FEE channels:
TPC: 30 pad-rows, 0.8x0.2 cm² read-out pad → ~1.2 x 10⁵

Barrel; TGEM with stereo-strip read-out, 400 μm pitch, 10x10, 10x10, 20x20 cm² detector size → ~1.3 x 10⁶
GEM

Thin, metal-coated polymer foil with high density of holes:

Typical geometry:
5 µm Cu on 50 µm Kapton
70 µm holes at 140 mm pitch

F. Sauli,

From F. Sauli presentation
MULTIPLE GEM STRUCTURES

Cascaded GEMs permit to attain much larger gains before discharge

Double GEM

Triple GEM

From F. Sauli presentation

Multiple structures provide equal gain at lower voltage.
The discharge probability on exposure to $\alpha$-particles is strongly reduced.

**DISCHARGE PROBABILITY WITH $\alpha$-particles**

For a gain of 8000 (required for full efficiency on minimum ionizing tracks) in the TGEM the discharge probability is not measurable.


From F. Sauli presentation.
FAST ELECTRON SIGNAL (NO ION TAIL)

The total length of the detected signal corresponds to the electron drift time in the induction gap:

Full Width 20 ns (for 2 mm gap)

Induced charge profile on strips
FWHM 600 µm

Good multi-track resolution

From F. Sauli presentation
GEM time resolution

Triple GEM with pad readout for LHCb muon detector


From F. Sauli presentation
**GEM DETECTOR:**

- multiplication and readout on separate electrodes
- electron charge collected on strips or pads: 2-D readout
- fast signal (no ion tail)
- global signal detected on the lower GEM electrode (trigger)

*A. Bressan et al, Nucl. Instr. and Meth. A425(1999)254*

From F. Sauli presentation
Two orthogonal sets of parallel strips at 400 µm pitch engraved on 50 µm Kapton 80 µm wide on upper side, 350 µm wide on lower side (for equal charge sharing)

From F. Sauli presentation
COMPASS TRIPLE GEM CHAMBERS

- Active Area 30.7 x 30.7 cm\(^2\)
- 2-Dimensional Read-out with 2 x 768 Strips @ 400 \(\mu\)m pitch
- 12+1 sectors GEM foils (to reduce discharge energy)
- Central Beam Killer 5 cm \(\phi\) (remotely controlled)
- Total Thickness: 15 mm
- Low mass honeycomb support plates

From F. Sauli presentation

Very good correlation, used for multi-track ambiguity resolution

X-Y Cluster charge correlation:

\[ \sigma \sim 10\% \]

From F. Sauli presentation
Space and Time Resolution

Space resolution:

Traks fit with two TGEM and one silicon micro-strip after deconvolution $\sigma = 46 \pm 3$ $\mu$m

Time resolution:

$\sigma = 57$ $\mu$m

$\sigma = 12.4$ $\text{ns}$

Time resolution: computed from charge signals in three consecutive samples (at 25 ns intervals) $\sigma = 12.4$ $\text{ns}$

From F. Sauli presentation
Pt and P reconstruction performance

Barrel, $|\eta| < 0.9$, $\theta = \{45. - 135.\}$ deg
DCA to primary vertex position (impact parameter), xy and rz

Barrel, $|\eta| < 0.9$, $\theta = \{45. - 135.\}$ deg, $Pt = \{1. - 60.\}$ GeV/c

<table>
<thead>
<tr>
<th></th>
<th>SiD</th>
<th>SiD + TPC</th>
<th>SiD (+ TPC) + VXD</th>
</tr>
</thead>
<tbody>
<tr>
<td>xy</td>
<td>0.0012</td>
<td>0.0013</td>
<td>0.0005</td>
</tr>
<tr>
<td>rz</td>
<td>2.8</td>
<td>0.05</td>
<td>0.0005</td>
</tr>
</tbody>
</table>

All numbers are in cm
+ VXD data

Barrel, $|\eta| < 0.9$, $\theta = \{45. - 135.\}$ deg
Pt and P reconstruction performance

Forward; $|\eta| = \{1.3 - 1.9\}$, $\theta = \{17 - 30\}$ deg.

$3$ Si $+ 4$ GEM

$4$ Si $+ 3$ GEM

$3$ Si $+ 4$ GEM

$4$ Si $+ 3$ GEM
Instead of Conclusion

• There is a point to be discussed
  • SiD + miniTPC is very powerful combination and can “solve all problems(!?)”
    - P reconstruction for both primary and secondary tracks
    - good matching with VXD and EMC
    - PID
  
• Additional (or may be “main”) approach for track finding (Pt > ?):
  - TPC track finding: reliable and efficient
  - matching with Si-detectors data, re-fit
  - crossing with VXD, Calorimeters, μ-detectors
  - select VXD hits, re-fit, use VXD hits to reconstruct vertex (s)

• Triple GEM Detectors with stereo-strips readout → Forward position
• miniTPC in Forward Direction ?
• low mass TPC construction with micropattern read-out should be demonstrated ( R&D is in progress ).
• GEM foil mass-production, test, calibration, passportization, ….
Fast, Compact TP with enhanced electron ID capabilities.
(R&D started)

Pad Detector with CsI Photocathode

16 identical modules with 35 pad-rows,
Double (triple) GEM readout with pad size: 0.2x1. cm².
Maximum drift: 40-45 cm.
Ion back-flow reduction: reversed-MHSP & GEM

F. Amaro et al. WIS/Coimbra IEEE 2004

**MHSP**: gain & ion blocking

**R-MHSP**: ion defocusing*

* S. Roth, Vienna 04

**IBF**: Ion Backflow Reduction

Multi-GEM: $IBF = 10^{-1} - 2 \times 10^{-1}$

Multi-GEM & MHSP: $IBF = 2 \times 10^{-2}$

R-MHSP & Multi-GEM & MHSP: $IBF = 1.3 \times 10^{-3}$

**IBF R&D IN PROGRESS!**

( Amos Breskin, WIS )
At slightly negative ED, photoelectron detection efficiency is preserved whereas charge collection is largely suppressed.

Hadron Blindness: UV photons vs. $\alpha$ particles

STAR upgrade / R&D proposal
Hadron blindness: Response to hadrons

(KEK beam test)

**Pulse Height**

- $E_D = 1.0 \text{ kV/cm}$
  - $\langle \text{charge} \rangle = 17.7 \text{ e}$

- $E_D = 0.25 \text{ kV/cm}$
  - $\langle \text{charge} \rangle = 18.0 \text{ e}$

**Charge Collection**

- Charge collected from 150$\mu$m layer above GEM

**Rejection Factor**

- Rejection factor limited by Landau tail

- $E_D$ switches polarity
- Charge collected from 150$\mu$m layer above GEM
- Rejection factor limited by Landau tail
Future e+e- LC Detector Set-Up. Large TPC OR Middle one + 
Gas Micro-Pattern and Si pad (strip) detectors ?!

- is it realistic to get a hit space resolution ~100 μm for so long drift?
- ExB corrections / alignment (Bz >= 4 T)
- space charge distortions; F(drift distance, time structure, fluctuations)
- field cage and construction materials thickness
- membrane (cathode) HV

Gas micro-pattern strip (stereo) detectors demonstrated very good performance
Low mass (and cost), fast, reliable, with space resolution ~40 μm
Convenient for alignment; TPC calibration and corrections, events pile up;
trigger possibilities (?!)
Two variants, Pt reconstruction performance comparison
(realistic thickness, GEANT, hit Gaussian smearing, Helix fit)

Rapidity = (+/- 0.8), Bz = 5 T

<table>
<thead>
<tr>
<th>Detector Type</th>
<th>$\sigma_{r\phi}$</th>
<th>$\sigma_z$ ((\mu)m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TPC (Ar+CF4)</td>
<td>100.</td>
<td>300.</td>
</tr>
<tr>
<td>GEM (strip stereo)</td>
<td>50.</td>
<td>700.</td>
</tr>
<tr>
<td>Si (strip stereo)</td>
<td>20.</td>
<td>600.</td>
</tr>
<tr>
<td>Si (vertex)</td>
<td>5.</td>
<td>6.</td>
</tr>
</tbody>
</table>

(20x20 \(\mu\)m² pads)
Hexaboard readout: matrix of hexagonal pads interconnected along three projections at 120°

Hexaboard closeup: 520 µm Ø pads

S. Bachmann et al

From F. Sauli presentation
SINGLE EVENT:

16 strips
8.3 mm

From F. Sauli presentation
CHARGE CORRELATION BETWEEN THE PROJECTIONS:

SINGLE CLUSTERS

U-V

W-U

V-W

From F. Sauli presentation
SINGLE PHOTON CLUSTER WIDTH (rms)

σ ~ 250 µm

Charge sharing (520 µm pad rows)

From F. Sauli presentation
TOTEM READOUT BOARD:
Radial strips (accurate track’s angle)
Pad matrix (fast trigger and coarse coordinate)

From F. Sauli presentation
Gain Curve: Triple GEM with CsI in CF$_4$:

Measured with Fe$^{55}$ and with UV lamp

- Gains in excess of $10^4$ are easily attainable.
- Voltage for CF$_4$ is $\sim$140 V higher than for Ar/CO$_2$ but slopes are similar for both gases.
- Gain increases by factor $\sim$3 for $\Delta V = 20$V.
- Pretty good agreement between gain measured with Fe55 and UV lamp.
STAR tracking upgrade. Possible variant with μTPC
(fast, low diffusion gas mixture; micropattern read-out; low-mass construction)

Central HJ event, miniTPC response simulation, first (in R) pad-row

Drift direction, cm

Read-out pads direction, cm

STAR TPC In-Field_cage

R = 50 cm
VXD in GEANT